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PAGE 1 OF	10	E-MAIL:	mark.robbins@eev.com
DATE:	26th July 1999	OUR REF:	

Dear Jim

I have just had a preliminary look at the radiation levels for FAME and I have the following comments that may be useful to you.

I understand from our conversation last week that FAME will be in a geostationary orbit (35,786 km) and that the launch date will be either 2003 or 2004. You wish to guarantee operation up to 2.5 years with a possible extension to 5 years. For this illustration I will consider the 5 year case with a launch at the start of 2003 which gives approximately 3 years within the solar maximum of cycle 23. I have estimated the radiation environment using "SpaceRadiation 4" and the results are attached as Figures 1 and 2.

With 10 mm of Al shielding the total ionising dose is about 4 krad(Si). This level of ionising dose can be easily handled giving a voltage shift of about 400 mV. Provided the device is correctly set up, the main effect you should observe is a slight reduction in the output circuit responsivity. (I am including a brief note on the ionising radiation effects with this FAX).

The NIEL equivalent 10 MeV proton fluence is calculated to estimate the bulk damage to the silicon. This is shown in figure 2. After 10 mm of Al shielding the lifetime proton fluence is approximately 6 10^9 p/cm^2.

The main radiation induced defect in the buried channel is the Si-E centre. The divacancy is also produced but at a rate roughly 15% that of the Si-E centre. Work for my thesis a few years ago, and presented at RADECS'91, measured the emission time constant for the Si-E centre. At -70 °C the emission time constant is roughly 250 ms. After 6 10^9 p/cm^2 the density of Si-E centres will be roughly 10^{11} cm^{-3}. These will be point defects (single electron traps) effectively randomly distributed through the silicon. The number of defects the signal will interact with is dependent on the volume occupied by the signal. Estimates based on extrapolation from larger pixels gives an effective signal density for a 1000 electron signal packet of very roughly 4 10^{14} cm^{-3}. This implies that a Si-E centre will be encountered about once every 4 transfers (ie through 1.3 pixels). For a 100,000 electron signal charge packet the effective signal density is roughly 3 10^{15} cm^{-3}. This implies that this larger charge packet will encounter about 3 Si-E centres every transfer.

A supplementary buried channel can be included to confine the small signals to a smaller volume. However, the effectiveness of this approach when dealing with small pixels has not been quantified and would need to be evaluated.

The bulk dark signal should also be considered but is obviously not particularly significant at -70 °C. The theoretical dark signal distribution after 6 10^{9} 10 MeV.p/cm^{2} is given in figure 3.

I hope this discussion is of some use to you. Please do not hesitate to call me if you would like to discuss this further.

Best regards

Mark

Dr Mark Robbins
CCD Applications and Radiation Specialist
Space and Communications Group

Figure 1.

5 year mission integrated ionising dose for geostationary orbit (3 years at solar maximum 2 years at solar minimum)

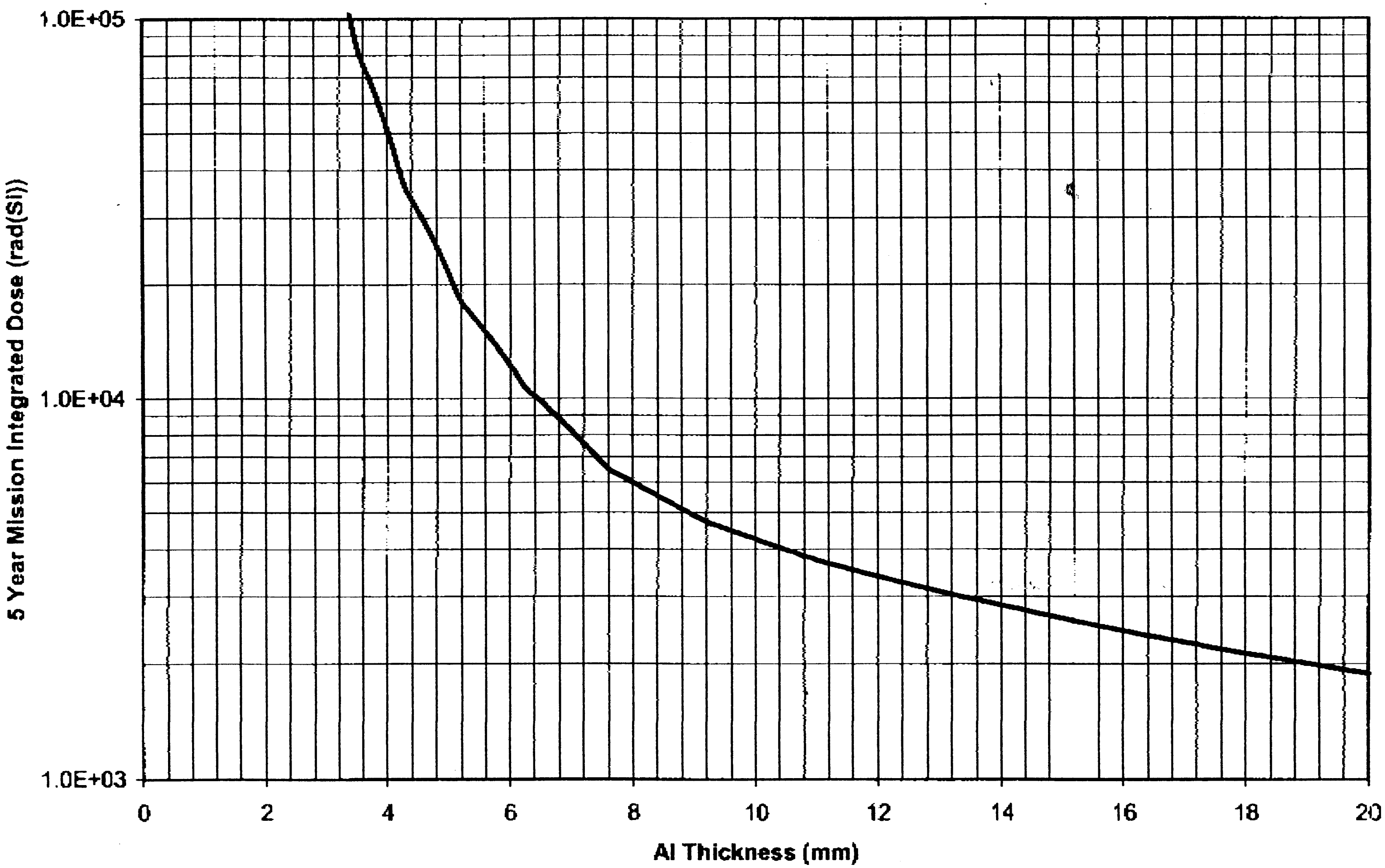

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Figure 2.

10 MeV NIEL eqivalent proton fluence for 3 years in geostationary orbit at solar maximum (JPL91 95% Confidence)

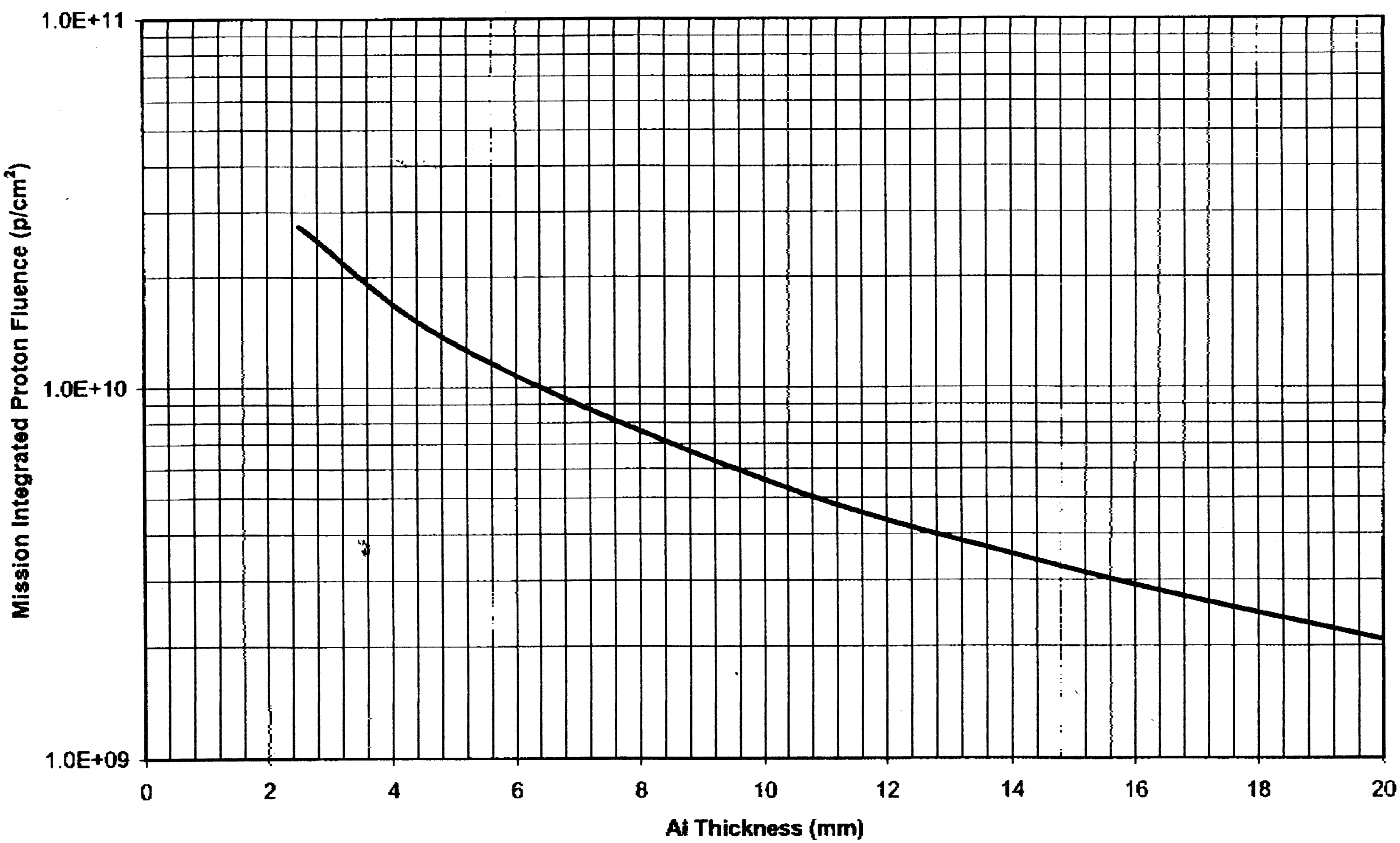

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Figure 3

Proton Fluence (cm^{-2})	6.00E+09
Proton Energy (MeV)	10
NIEL (keV cm^2/g)	7.8848
Pixel Width (µm)	15
Effective Pixel Width (µm)	11.5
Pixel Height (µm)	15
Depletion Depth (µm)	8
Temperature (K)	203

Elastic Interaction	
Cross section (barns)	1847.5
Damage Energy (keV)	0.1784
Damage Variance $(keV)^2$	4.545
Mean number of events/pix	763.0293

Inelastic Interaction	
Cross section (barns)	0.6127
Damage Energy (keV)	60.21
Damage Variance $(keV)^2$	1309.76
Mean number of events/pix	0.253049

Calculated Bulk Dark Sig (nA/cm^2)	1.321E-05
Calculated DSNU (nA/cm^2)	5.993E-06
Calculated DSNU (%)	45.37319